Pergamon

RWLP0239

Environment International, Vol. 25, No. 4, pp. 443–450, 1999
copyright©1959Elsevier Science Ltd
Printed in the USA. All rights reserved
0160-4120/99/$–see front matter

PII S0160-4120(99)00019-7

INDOOR AND OUTDOOR AIR QUALITY INVESTIGATION AT 14 PUBLIC PLACES IN HONG KONG

SC. Lee, L.Y. Chan, and M.Y. Chiu
Environmental Engineering Unit, Department of Civil and Structural Engineering, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong

EI 9805-153 M (Received 21 May 1998; accepted 25 November 1998)

The indoor and outdoorairquality of 14 public places with mechanical ventilation systems in Hong Kong were investigated from October 1996 to March 1997. Fourteen public places located in urban residential, commercial, industrial, and rural areas were selected for indoor/outdoor (I/O) air pollutant measurement. The public places included restaurants, libraries, recreation places, shopping malls, sport centers, and a car park. The concentrations of SO_2, CO, CO_2, NO, NO_x, total hydrocarbons (THC), and particulate matter (PM_{10}) were measured during peak traffic hours at each sampling location. I/O correlations between indoor and outdoor air quality were performed. High I/O ratios of CO, CO_2, THC, and PM_{10}, were due to a high infiltration rate and the presence of indoor sources. The results show that the I/O ratios at public places were higher than those at homes and offices. Insufficient ventilation caused high CO, levels. The I/O ratios of PM_{10} and CO at public places where tobacco smoking is permitted were 4 times and 1.6 times those where smoking is prohibited. ©1999 Elsevier Science Ltd

INTRODUCTION

Environmental awareness rises with the affluence of the society as more people are seeking higher living standards and a better working environment. Indoor air quality (IAQ) has become a great concern in recent years, and the ventilation system of a building is the key factor affecting the IAQ.

Recently, a number of studies have evaluated the correlation between indoor and outdoor air pollution. Ando et al. (1996) suggested that the concentration of suspended particulate matter in indoor air increased in proportion to that in outdoor air. Dockery and Spengler (1981) indicated that the concentration of fine particulate matter in indoor air was affected by outdoor air, and the mean infiltration rate was found to be approximately 70%. Kim and Stock (1986) agreed that indoor aerosol appears to be affected by the infiltration of outdoor air as well as by indoor generation. The indoor/outdoor (I/O) relationship can be established for those pollutants that originate from the outdoors and most of the studies reported residential indoor to outdoor ratios less than 1.

Other studies evaluated the infiltration of pollutants in different communities. Li (1994) found that indoor total suspended particles (TSP) and particulate matter (PM_{10}) concentrations were well correlated with the corresponding outdoor level in residential and industrial communities ($R^2 = 0.99$) and their I/O ratios were 0.6. Lee (1997) investigated the indoor and outdoor air quality at two staff quarters in Hong Kong and found that indoor CO concentrations were systematically higher than those outdoors on weekdays as well as on Sundays. Except for CO, all other measured pollutants had indoor concentrations lower than outdoor. Liao et al. (1991) observed that the air quality of street level shops with open fronts is overwhelmingly influenced by vehicular emissions and poor ventilation conditions.

PM3006519153

Source: https://www.industrydocuments.ucsf.edu/docs/pmgj0001

Table 1. General descriptions of 14 public places.

Nature	Site no.	Type	Indoor source	Outdoor source
Restaurant	RE1	urban commercial	gas stoves	construction activity
Restaurant	RE2	urban residential		heavy traffic
Restaurant	RE3	rural		construction activity
Library	LI1	urban commercial	photocopiers	car park exhaust and heavy traffic
Library	LI2	rural		-
Recreation place	RP1	urban commercial	tobacco smoke and burning incense	heavy traffic
Recreation place	RP2	urban residential		heavy traffic
Recreation place	RP3	urban commercial		diesel piling and vehicle exhaust
Shopping mall	SM1	urban residential	tobacco smoke	construction activity and heavy traffic
Shopping mall	SM2	urban commercial		
Shopping mall	SM3	urban industrial	painting	
Sport center	SC1	urban commercial	-	construction and motor vehicle exhaust
Sport center	SC2	rural	-	-
Car park	CP1	urban commercial	vehicle engine	motor vehicle exhaust

They also found that the CO_2 levels in offices were in excess of 1000 μL/L in almost 30% of the offices investigated, resulting in complaints of sick-building syndrome.

The effects of environmental tobacco smoking (ETS) on indoor and outdoor air quality are also a subject of interest. Quackenboss et al. (1989) studied the effect of indoor and outdoor air pollutants with and without ETS, and the I/O ratios were 0.63 for non-smoking homes and 1.1 for smoking homes. Ott et al. (1996) studied the particulate matter concentration inside a tavern before and after the prohibition of smoking. The results showed that the average respirable suspended particles (RSP) concentration was 56.8 μg/m^3 above the outdoor concentrations during the smoking period, but the average abruptly dropped to 5.9 μg/m^3 above the outdoor level after smoking ceased. That is, a 90% decrease in the indoor PM_{10} level.

The objective of this study was to investigate the relationship between indoor and outdoor air pollutants at 14 public places in Hong Kong. Eight pollutants, including NO_2, NO, NO_x, SO_2, CO, CO_2, total hydrocarbons (THC), and respirable suspended particulate matter (PM_{10}) were measured indoor and outdoor simultaneously at each public place. The I/O relationship at these public places was analysed and compared. The concentration of indoor pollutants with and without tobacco smoking was also investigated.

FIELD STUDY

Fourteen public places were selected from different geographic categories representing different environments (urban commercial, residential, industrial, and rural). The potential outdoor sources of pollutants at these public places included motor vehicles and construction activities; while the indoor sources were from gas stoves, photocopiers, tobacco smoking, incense burning, painting, and indoor engine exhaust. Table 1 lists the general descriptions of the 14 public places including 3 restaurants (RE1, RE2, and RE3), 2 libraries (LI1 and LI2), 3 recreation places (RP1, RP2, and RP3), 3 shopping malls (SM1, SM2, and SM3), 2 sport centers (SC1 and SC2), and 1 carpark (CP1). Mechanical ventilation was provided by central air conditioning at the 14 public places and they are located at the ground floor to the third floor. In particular, SM1, SM2, and SM3, with front doors opened during business hours, were seriously affected by heavy traffic pollutants.

Sampling methodology

Indoor and outdoor air samples were collected from October 1996 to March 1997 at the 14 public places. During sampling, indoor air samples were collected at the most densely occupied area, while outdoor air samples were taken near the fresh air intake during peak hours. Temperature, humidity, CO_2, and PM_{10} were measured by portable analyzers, and CO, NO, NO_2, SO_2, and THC were collected using Teflon bags and then shipped back to the laboratory for further analysis. TSI Portable Q-TRAK (Model 8550) and DUST-TRAK (Model 8520) were used to record the real-time temperature, relative humidity, CO_2, and PM_{10} measurements, respectively, at 15-min intervals.

PM3006519154

Source: https://www.industrydocuments.ucsf.edu/docs/pmgj0001

The simultaneous indoor and outdoor air samples were obtained using Teflon bags and SKC pumps (Airchek sampler, Model 224-43xR). Samples were collected at a flow rate of 1 L/min for 20 min and at the breathing zone (i.e., 1.5 m above the ground). All air samples were immediately transported to the laboratory for analysis. The CO, NO, NO_2, SO_2, and THC were measured in the laboratory by a Gas Filter Correlation CO Ambient Analyzer (Thermo Electron Model 48, range: 0-1000 μL/L, Precision: 1 nL/L), a Chemiluminescence NO-NO_2-NO_x Analyzer (Thermo Electron Model 42, range: 0-20 μL/L, precision: 0.5 nL/L), a Pulsed Fluorescence SO_2 Analyzer (Thermo Electron Model 43B, range: 0-100 μL/L, precision: 1 nL/L), and an APHA-300E Ambient HC Monitor (HORIBA Ltd., detection limit: 0.1 μL/L, precision: ±0.1 nL/L), respectively, in the laboratory. The effect of time lag on the concentration measurement of pollutants is negligible (error less than 1% for SO_2, NO, NO_2, and CO) if the samples were measured within 3 h after they were collected and transported to the laboratory.

As a quality control measure, Q-TRAK and DUST-TRAK were calibrated before sampling using zero air and standard span gas. Teflon bags were flushed with zero air twice before sampling. During delivery to the laboratory, the sampling bags were contained in black plastic bags to avoid direct illumination of sunlight. Samples were immediately sent to the laboratory within an hour after sampling. All the bench top analyzing instruments were calibrated regularly with NIST traceable calibration gases.

RESULTS AND DISCUSSION

As shown in Fig. 1, the average indoor and outdoor concentrations of SO_2, CO, CO_2, NO, NO_2, THC, and PM_{10} measured at the 14 public places were compared with the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE 1989) standard for indoor air pollutants and the USA National Ambient Air Quality Standard (NAAQS 1992) for outdoor air pollutants.

Both indoor and outdoor levels of SO_2 and CO at the 14 public places were much lower than the standards of ASHRAE and NAAQS. The highest indoor and outdoor SO_2 concentrations (0.012 μL/L and 0.0093 μL/L, respectively) were observed in RP3 where a diesel-powered piling machine generated a large amount of SO_2 outdoors. The concentrations of SO_2 at sites in rural areas such as RE3, LI1, and SC2 were about half the concentration in urban areas. The source of SO_2 was mainly diesel vehicle exhaust and industrial emissions. In Hong Kong, the content of sulphur in fuel is tightly controlled by the government, thus, sulphur dioxide in the atmosphere has been greatly reduced in recent years. The differences between indoor and outdoor SO_2 concentrations were small and most of the public places have the same levels of SO_2 both indoors and outdoors. Higher CO levels were observed indoors than outdoors at smoking places and the car park.

Six public places (RP2, RP3, SM1, SM2, RE1, and RE2), with indoor CO_2 levels over 1000 μL/L (ranged from 1166 to 2229 μL/L), exceeded the ASHRAE standard. The high CO_2 levels at these six public places were due to the high population density and the presence of tobacco smoking. According to the ASHRAE guideline, CO_2 (produced mainly from human exhalation) exceeding 1000 μL/L might cause sick building syndrome (Liao et al. 1991).

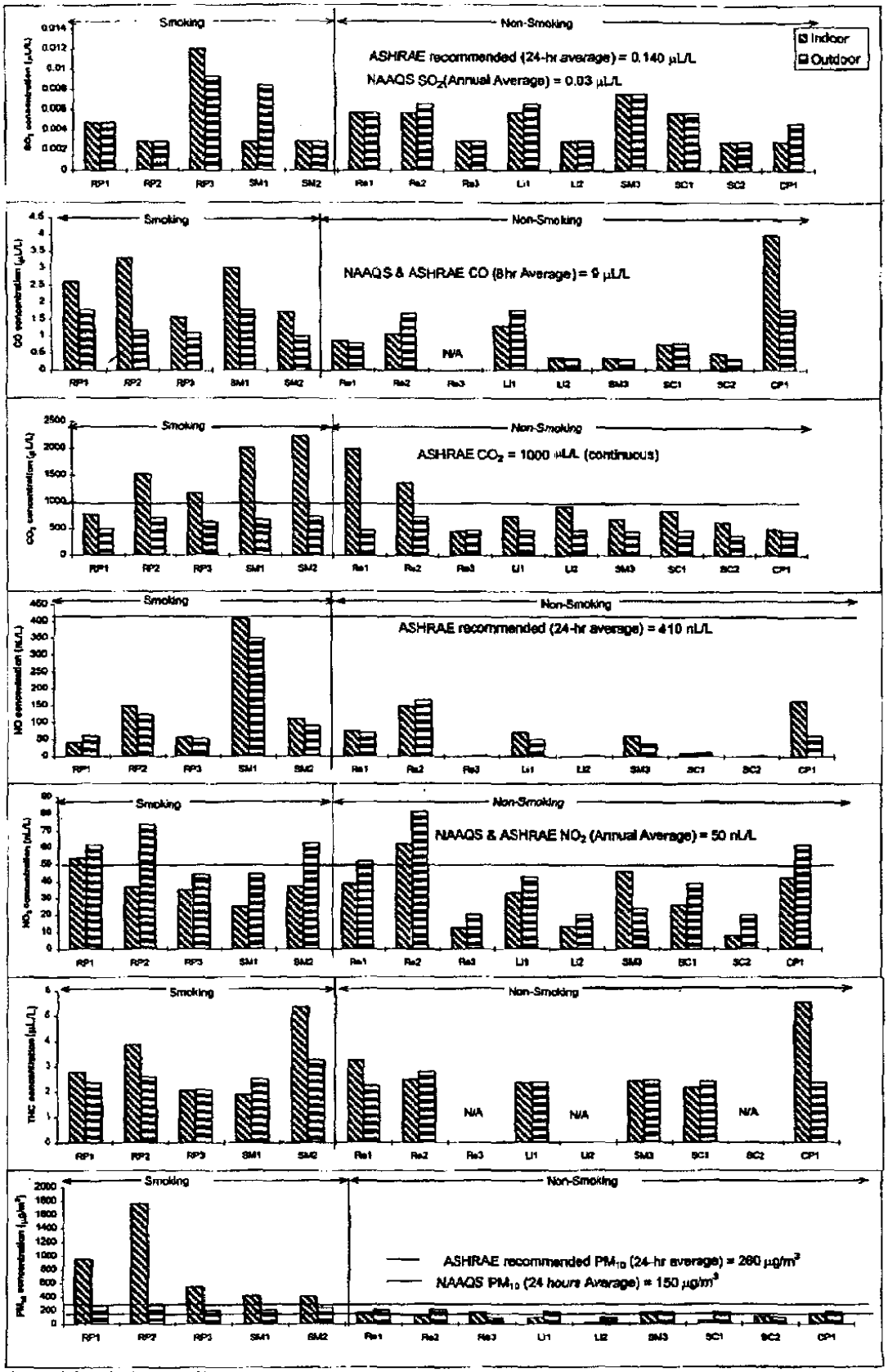
The NO level at SM1 reached 407 nL/L, near the ASHRAE standard (410 nL/L), and all public places were below the standard. Fourteen percent of the indoor and 43% of the outdoor NO_2 concentrations exceeded the NAAQS (50 nL/L, annual average). Among the 14 public places, indoor NO_2 levels varied from a minimum of 7.74 nL/L in the rural sports centre (SC2) to a maximum of 62.18 nL/L in the urban restaurant (RE2). All indoor NO_2 levels were lower than outdoor concentrations except at SM3. SM3 had a high NO_2 level because there are many opening exits at the ground level and second floor adjacent to heavily trafficked roads. The high infiltration rate of outdoor air pollutants resulted in the worst air quality inside the building. Thus, the indoor pollutant concentrations at SM3 were higher for CO_2, NO, and NO_2, or approximately equal for SO_2, CO, THC, and PM_{10}, when compared with those outdoors.

Outdoor THC levels at the 11 public places had little variations except at CP1, SM2, and RP2. The outdoor THC concentrations ranged between 1.87 and 3.25 μL/L; while the range of indoor THC levels was from 1.83 to 5.56 μL/L. The highest THC level was found in CP1. Potential THC sources were vehicle exhaust emission and cleaning solvents.

Five public places with tobacco smoking (RP1, RP2, RP3, SM1, and SM2) exceeded the indoor PM_{10} standard (260 μg/m^3, 24-h average) recommended by ASHRAE, while 79% PM_{10} of the outdoor air exceeded NAAQS (150 μg/m^3, 24-h average). Only a few sites had PM_{10} concentrations below the NAAQS and the maximum PM_{10} measured was as high as 1760 μg/m^3

PM3006519155

Source: https://www.industrydocuments.ucsf.edu/docs/pmgj0001



* studied site with tobacco smoking
N/A = Not Available

Fig. 1. I/O pollutant concentrations at 14 public places.

Source: https://www.industrydocuments.ucsf.edu/docs/pmgj0001

PM3006519156

at RP2. However, it must be noted that the measurements were taken during peak hours where traffic activity is relatively high and outdoor samples were taken near the trafficked road. Incense burning and high tobacco smoking at the three recreation places were the cause for high indoor PM_{10} levels. All outdoor PM_{10} concentrations exceeded the standard except sites at rural areas (RE3, LI2, and SC2). The source of PM_{10} is mainly from diesel-driven motor vehicles in Hong Kong which explains why PM_{10} in rural areas are less important.

The range of the average I/O ratios for different pollutants (0.75-1.77) observed in this study was higher than in previous studies. The median I/O ratios of different pollutants at the staff quarters, including NO_x, NO, NO_2, SO_2, CO, and O_3, ranged from 0.72 to 1.29 (Lee 1997); the average I/O ratio of SO_2 at two departments of a university was 0.22 (Li and Harrison 1990); the median I/O ratio was 0.63 for PM_{10} at homes (Quackenboss et al. 1989). It might be due to high human occupancy, high infiltration rate, poor maintenance and operation of the ventilation system, and the presence of other sources at indoor public places.

I/O ratios and correlation

The I/O ratio is an indicator for evaluating the difference between indoor and outdoor levels, and their correlation can imply a source relationship between indoor and outdoor environments. The relationships between the indoor and outdoor levels of SO_2, CO, CO_2, NO, NO_2, THC, and PM_{10} are presented in Fig. 2. The values of the I/O ratio of each pollutant and their R^2 values are presented and summarized in Table 2. From Table 3, the average I/O ratios of NO and SO_2 were approximately equal to 1; the average I/O ratios of CO, CO_2, THC, and PM_{10} were larger than 1, while the average I/O ratio of NO_2 was smaller than 1. Among these pollutants, only NO has an R^2 larger than 0.7 (R^2=0.92), which means that the indoor NO concentration is well correlated with the corresponding outdoor level. The other pollutants (SO_2, CO, CO_2, NO_2, THC, and PM_{10}) were less correlated with their corresponding outdoor concentrations (range of R^2=0.23-0.59).

For an average I/O ratio approximately equal to 1, the average I/O ratio of NO was 0.99. The high correlation implies that NO was from the infiltration of outdoor motor vehicle exhaust. Since most of the NO_2 in the urban environment is formed through the reaction of NO with ozone and other minor constituents, especially in the presence of sunlight, the average I/O ratio for NO_2 tends to be less than 1 in the absence of indoor sources of NO_2 (Yocom 1982). SO_2 had an I/O ratio approximately equal to 1, but its correlation is poor. For average I/O less than or equal to 1, the results showed that the source of NO, NO_2, and SO_2 came from outdoors, especially from motor vehicle exhaust, and the indoor source can be neglected for these pollutants.

For average I/O larger than 1, CO, CO_2, THC, and PM_{10} had a poor correlation (0.23-0.51) between indoor and outdoor. High average I/O ratios of CO were found at CP1 and places with tobacco smoking (RP1, RP2, RP3, SM1, and SM2) and incense burning (RP1, RP2, and RP3). Ground level public places, such as RP, are at roadside with heavy motor vehicle traffic, which resulted in CO from engine exhaust easily infiltrated into the public places. The high density of tobacco smoking and incense burning presented in small occupied places in recreation places caused the high I/O ratio of CO. RP1 and RP2 had I/O ratios of 1.46 and 2.89 for CO, respectively. The considerably high I/O ratio (2.24) of CO at CP1 might come from the incomplete combustion of car engines, especially during the warming-up stage. The high I/O ratio (1.77 on average, R^2=0.51) of CO_2 reflected that the air exchange rate in the public places, especially recreation places, is insufficient.

The average I/O ratio of THC was 1.24 and the range of I/O ratios was 0.75-2.37. Poor correlation between indoor and outdoor THC levels (R^2=0.226) showed that the THC level was not only affected by the outdoor environment, but is also affected by the presence of indoor sources such as building construction materials, carpets, tobacco smoke, gas stoves, and cleaning products.

The average I/O ratio of PM_{10} was 1.67 and the highest I/O ratio was observed at RP because of the presence of tobacco smoking and incense burning at these areas. The results showed that PM_{10} is significantly related to tobacco smoking indoors. Without tobacco smoking, the I/O ratio was less than 1 (LI, SC, and CP) while I/O was greater than 1 with smoking (RP and SM). Restaurants also had an I/O ratio greater than 1 due to heating and cooking.

The I/O ratios of CO, CO_2, THC, and PM_{10} were larger than 1 when there were indoor sources. Poor correlations of these four pollutants were found because indoor air quality at different places is affected by different indoor sources and some public places are only affected by outdoor sources.

PM3006519157

Source: https://www.industrydocuments.ucsf.edu/docs/pmgj0001

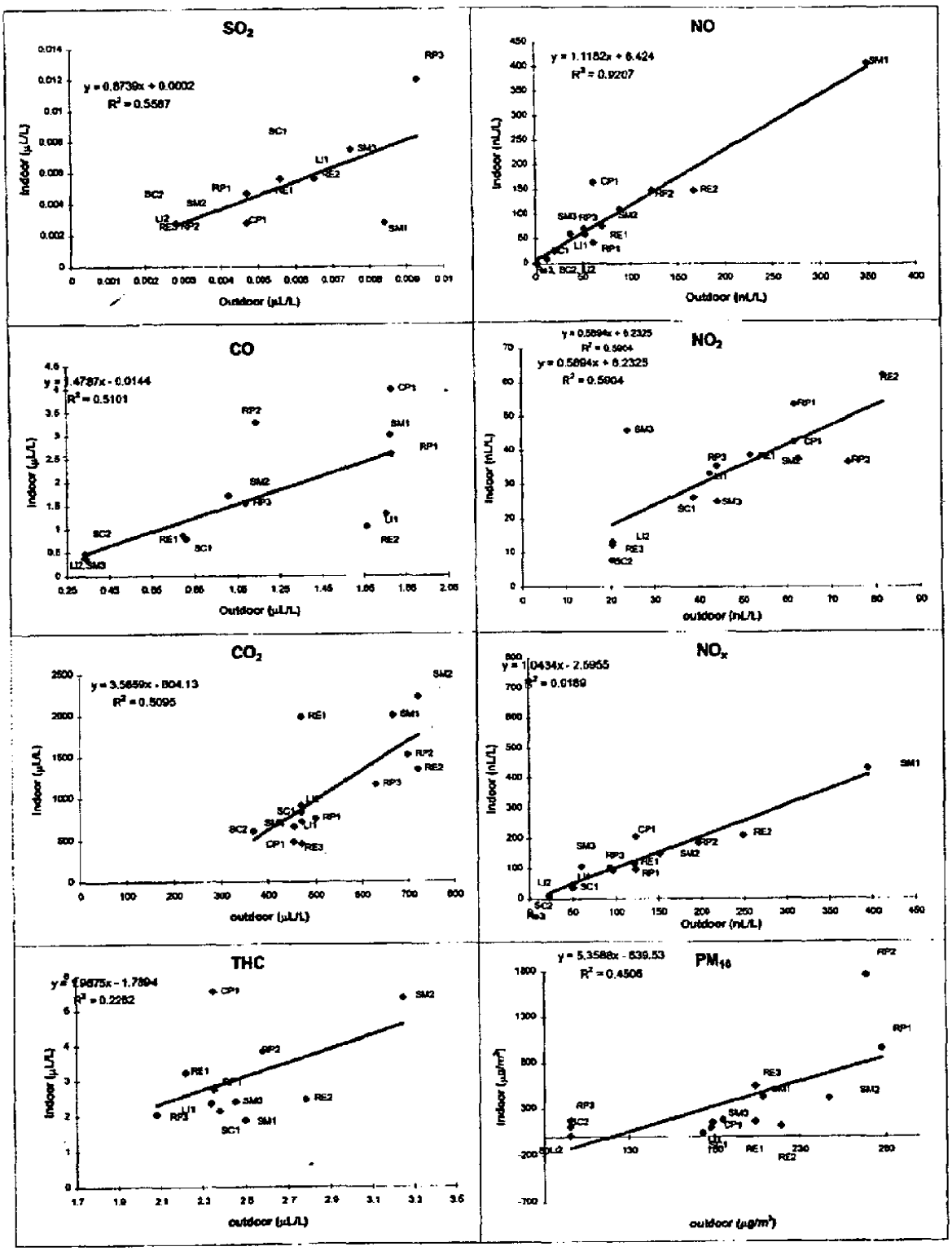


Fig. 2. Correlation of I/O concentration for different pollutants.

Source: https://www.industrydocuments.ucsf.edu/docs/pmgj0001

PM3006519158

Table 2. Values of I/O ratio and R^2 for different pollutants at 14 studying sites.

Public places	SO_2	CO	CO_2	NO	NO_2	NO_x	THC	PM_{10}
RE	0.95	0.86	2.36	0.99	0.70	0.78	1.17	1.06
LI	0.93	0.93	1.75	1.38	0.72	0.86	1.00	0.34
RP	1.10	1.93	1.85	1.00	0.72	0.89	1.21	4.22
SM	0.78	1.51	2.52	1.35	1.03	1.28	1.13	1.56
SC	1.00	1.20	1.73	0.83	0.53	0.53	0.90	0.70
CP	0.60	2.24	1.07	2.68	0.69	1.68	2.37	0.87
Average I/O ratio	0.92	1.42	1.77	0.99	0.75	0.94	1.24	1.67
R^2	0.557	0.510	0.510	0.921	0.590	0.919	0.226	0.451

Table 3. Summary of I/O ratio and R^2 for pollutants.

	$R^2 > 0.7$	$R^2 < 0.7$
I/O ~ 1	NO, NO_x	SO_2
I/O > 1	-	CO, CO_2, THC, RSP
I/O < 1	-	NO_2

Indoor and outdoor levels of public places with and without tobacco smoking

In this study, five out of fourteen public places had tobacco smoking sources indoors. From Fig. 1, it was observed that PM_{10} and CO were closely related to tobacco smoking and the other pollutants were slightly affected by tobacco smoking. PM_{10} and CO levels with tobacco smoking indoors were significantly higher than that without tobacco smoking. The average I/O ratio of PM_{10} for tobacco smoking indoors was higher than that without tobacco smoking. The average I/O ratio of PM_{10} for tobacco smoking indoors was 3.15, which was 4 times the average I/O ratio for non-smoking (the average I/O ratio was 0.78). Also, the average I/O ratio of CO for the smoking premises was 1.83, which was 1.6 times that of the non-smoking premises. Quackenboss et al. (1989) found that the median I/O ratio of PM_{10} was 0.63 (range 0.3-3.4) without smoking and the median I/O ratio was 1.2 (range 0.3-4.7) with smoking. Higher smoking and non-smoking I/O ratios were obtained in the present study than in Quackenboss's study.

CONCLUSIONS

This preliminary study of indoor air quality inside public buildings in Hong Kong showed that outdoor PM_{10} levels were relatively high and most of them exceeded the NAAQS standards. The PM_{10} sources mainly come from vehicle emissions at heavily trafficked roads. The indoor air quality of public places is greatly affected by the outdoor air quality due to poor ventilation systems. Ventilation conditions in public places are often insufficient as demonstrated by the CO_2 levels in excess of 1000 μL/L in almost 43% of the public places. For an average I/O ratio approximately equal to or less than 1, the indoor air quality was mainly affected by outdoor sources, while for an average I/O ratio greater than 1, indoor sources were present. Poor correlation of indoor and outdoor pollutants was obtained because the sources affecting indoor air quality are inconsistent in all public places. Tobacco smoking is closely related to elevated indoor CO and PM_{10} levels. The results showed that public places allowing tobacco smoking had higher I/O ratios of CO and PM_{10} than those without tobacco smoking.

Acknowledgment—This research is sponsored by Research Project 351/861 of the Hong Kong Polytechnic University (HKPU). The authors would like to thank Mr. Kelvin Kam for preparation and analysis of IAQ samples, and Mr. W.F. Tam for technical support in the laboratory.

REFERENCES

Ando, M.; Katagiri, K.; Tamura, K.; Yamamoto, S.; Matsumoto, M.; Li, Y.F.; Cao, S.R.; Ji, R.D.; Liang, C.K. Indoor and outdoor air pollution in Tokyo and Beijing Supercities. Atmos. Environ. 30: 695-702; 1996.

ASHRAE (American Society of Heating, Refrigerating and Air Conditioning Engineers). Standard 62-1989. Ventilation for acceptable indoor air quality. Atlanta, GA: ASHRAE; 1989.

Dockery, D.W.; Spengler, J.D. Indoor-outdoor relationships of respirable sulfates and particles. Atmos. Environ. 15: 335-343; 1981.

Kim, Y.S.; Stock, T.H. House-specific characterization of indoor and outdoor aerosol. Environ. Int. 12: 75-92; 1986.

Lee, S.C. Comparison of indoor and outdoor air quality at two staff quarters in Hong Kong. Environ. Int. 23: 791-797; 1997.

PM3006519159

Source: https://www.industrydocuments.ucsf.edu/docs/pmgj0001

Li, C.S. Relationships of indoor/outdoor inhalable and respirable particles in domestic environments. Sci. Total Environ. 151: 205-211; 1994.

Li, Y.Q.; Harrison, R.M. Comparison of indoor and outdoor concentrations of acid gases, ammonia and their associated salts. Environ. Technol. 11: 315-326; 1990.

Liao, S.S.T.; Shone, J.B.; Kim, Y.S. Factors influencing indoor air quality in Hong Kong: Measurements in offices and shops. Environ. Technol. 12: 737-745; 1991.

NAAQS (National Ambient Air Quality Standard). 40 CFR Parts 1-50: 650-730; 1992.

Ott, W.; Switzer, P.; Robinson, J. Particle concentrations inside a tavern before and after prohibition of smoking: Evaluating the performance of an indoor air quality model. J. Air Waste Manage. Assoc. 46: 1120-1134; 1996.

Quackenboss, J.J.; Lebowitz, M.D.; Crutchfield, C.D. Indoor-outdoor relationships for particulate matter: Exposure classifications and health effects. Environ. Int. 15: 353-360; 1989.

Yocom, J.E. Indoor-outdoor air quality relationships, a critical review. J. Air Pollut. Contr. Assoc. 32: 500-520; 1982.

PM3006519160

Source: https://www.industrydocuments.ucsf.edu/docs/pmgj0001